

The dependence of the mass–size relation of early-type galaxies on environment in the local Universe

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ABSTRACT

The early-type galaxy (ETG) mass–size relation has been largely studied to understand how these galaxies have assembled their mass. One key observational result of the last years is that massive galaxies increased their size by a factor of a few at fixed stellar mass from $z \sim 2$. Minor mergers have been put forward in hierarchical models as a plausible driver of this size growth. Some of these models, predict a significant environmental dependence in the sense that galaxies residing in more massive halos tend to be larger than galaxies in lower mass halos, at fixed stellar mass and redshift. At present, observational results of this environmental dependence have been contradictory. In this paper we revisit this issue in the local Universe, by carefully investigating how the sizes of massive ETGs depend on large-scale environment using an updated and accurate sample of massive ETGs ($> 10^{11}$) in different environments - field, group, clusters - from the Sloan Digital Sky Survey DR7.

Observations do not show any environmental dependence of the sizes of central and satellites ETGs at fixed stellar mass. The size-mass relation of early-type galaxies seems to be universal, i.e., independent of the mass of the host halo and of the position of the galaxy in that halo (central or satellite). We compare

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our observational results with two hierarchical models built from the Millennium Simulation. Once observational errors are properly included in model predictions, we find our results to broadly agree (at $1 - 2\sigma$ level) with one of the models, but strongly disagree with the other (at $\sim 3\sigma$ level), proving how useful environment is in testing galaxy evolution models.

Subject headings: galaxies: elliptical and lenticular, cD, galaxies: halos, galaxies: clusters, galaxies: groups

1. Introduction

The study of scaling relations at low and high redshift (e.g. Bernardi et al. 2010, 2011; Shankar et al. 2010) is a powerful tool to constrain models of galaxy evolution. In particular, the mass-size relation has been largely studied in the recent literature. One key observational result arising from many of these works is that massive galaxies experienced a strong size evolution in the last 10 Gyrs, e.g., a significant fraction of them increased their size by a factor 2-3 from $z \sim 1$ and by $3 \sim 5$ from $z \sim 2$ (e.g. Daddi et al. 2005; Trujillo et al. 2006; van der Wel et al. 2008; van Dokkum et al. 2008; Buitrago et al. 2008; Damjanov et al. 2011; Cimatti et al. 2012; Huertas-Company et al. 2012; Raichoor et al. 2012; Mei et al. 2012).

Models of galaxy formation have proposed two main mechanisms to increase the size of early-type galaxies (ETGs). Fan et al. (2008) proposed mass loss via AGN feedback as the main process responsible for galaxy expansion (expansion scenario) while Hopkins et al. (2009) and Naab et al. (2009) argued that minor dry mergers are the most efficient mechanism (see also Shankar et al. 2013). Since both mechanisms act in very different time scales (e.g. Ragone-Figueroa et al. 2012) and leave different imprints in the galaxy structure (e.g. Hopkins et al. 2009), these observables have been largely used to constrain the models. Observational evidence clearly supporting one of the above theoretical proposals is still debated in the literature. On the one hand, Trujillo et al. (2011) reported that the low scatter in the ages of galaxies is difficult to reconcile with the fast growth predicted by the expansion scenario and van Dokkum et al. (2010); Patel et al. (2012) among others showed that galaxies grow inside-out and increase their sersic index which are clear predictions of the merger models. On the other hand, Ascaso et al. (2011) for instance, claim significant evolution in size but no in Sersic index for Brightest Cluster Galaxies (BCGs), supporting an expansion scenario rather than a merger-driven one. Also, Newman et al. (2012) reported recently that only if a short dynamical time scale is assumed, mergers alone can explain the growth shown by the data from $z \sim 1$ (see also López-Sanjuan et al. 2012) and

Huertas-Company et al. (2012) showed that several state-of-the-art semi analytical models struggle to fully reproduce the size evolution for galaxies at fixed $\log(M_*/M_\odot) > 11.2$ (see also Nipoti et al. 2012). The exact abundance of compact galaxies in the local Universe is still debated (e.g. Valentinuzzi et al. 2010, Poggianti et al. 2012, Trujillo et al. 2009) and the impact of newly born galaxies is not fully understood (e.g. Newman et al. 2012, López-Sanjuan et al. 2012, Kaviraj et al. 2013). The morphological evolution of these massive galaxies and how it affects size evolution is also unclear (e.g. Buitrago et al. 2011, Huertas-Company et al. 2012, van der Wel et al. 2011, van Dokkum et al. 2011).

Environment, is another powerful observable which can shed new light into the puzzle. In fact, some hierarchical models predict a significant environmental dependence in the sense that galaxies residing in more massive halos tend to be larger than galaxies in lower mass halos, at fixed stellar mass and redshift (e.g. Shankar et al. 2013). Unfortunately, observational studies at different redshifts have led to controversial results. Three works at $z \sim 0$, $z < 0.4$ and $z \sim 1.2$ (Weinmann et al. 2009; Maltby et al. 2010; Rettura et al. 2010) did not find any significant trend of the mass–size relation with environment. Valentinuzzi et al. (2010) found however a high fraction of *super dense galaxies* in clusters in the local Universe, a result that is confirmed by Poggianti et al. (2012) who also claimed that early-type galaxies in clusters are slightly smaller than those living in the field at fixed stellar mass. At $z \approx 1.3$, Raichoor et al. (2012) studied a sample of morphologically selected early-type galaxies in three different environments (field, cluster, groups) and found that, on average, for masses $10 < \log(M/M_\odot) < 11.5$ cluster galaxies have either the same size or appear to be smaller at fixed stellar mass than field galaxies, depending on the stellar population model used. More recently, Huertas-Company et al. (2012) did not detect any correlation with environment below $z \sim 1$ up to the group scale ($\log(M_h/M_\odot) < 14$). On the other hand, in the same stellar mass range but using a different definition for environment, Cooper et al. (2012) found exactly the opposite trend. Larger sizes in the cluster environment are also observed at $z = 1.62$ by Papovich et al. (2012) for passive galaxies with stellar masses larger than $\log(M/M_\odot) \sim 10.5$. The differences between these works are still to be understood and might come from different sample selections and/or the way environment is measured and/or low statistics at high redshift.

In this paper, we revisit this issue by carefully studying the mass-size relation of central and satellites ETGs in different environments selected from the Sloan Digital Sky Survey (SDSS) DR7 (Abazajian et al. 2009) with an updated and accurate sample. The large statistics available make the SDSS the best sample to probe the environmental dependence of galaxy sizes. We probe an halo mass range $12 < \log(M_h/M_\odot) < 15$. The SDSS observations are compared to predictions from the standard cosmological model, Λ CDM, obtained from the Guo et al. (2010) semi-analytical model and from the Shankar et al. (2013) model.

2. ETG sample selection

We selected our ETG galaxy sample from the Sloan Digital Sky Survey DR7 spectroscopic sample (Abazajian et al. 2009). We select galaxies with an early-type morphology based on the galaxy morphological classification from Huertas-Company et al. (2011)¹. The authors performed a bayesian automated classification of the full SDSS DR7 spectroscopic sample based on support vector machines and associated to every galaxy a probability to be in four morphological classes (E, S0, Sab and Scd). In this work we select as ETGs those objects with a probability to be early-type (E or S0) greater than 0.8. Results do not change significantly if the probability threshold is changed between 0.5 and 0.8.

To probe haloes of different mass, we use the group and cluster galaxy sample from Yang et al. (2007), updated to the DR7.² This catalog of $\sim 300,000$ clusters and groups ($\sim 30,000$ with more than 2 members) has been built using an automated halo-based group finder and provides an estimate of the halo mass in which galaxies live. For this work, we restricted the analysis to groups with $z < 0.09$ (for completeness reasons) and at least two members and also removed those objects affected by edge effects ($f_{edge} < 0.6$). With this selection we expect that $\sim 80\%$ of these groups have less than $\sim 20\%$ contamination from interlopers (Yang et al. 2007). We use as halo mass estimate, HM1, which is based on the characteristic luminosity of the group but results remain unchanged when using an halo mass estimate based on the characteristic stellar mass. The expected uncertainties on halo masses are 0.2-0.3 dex according to fig. 7 of Yang et al. (2007) in which they compare estimated to true halo masses from a mock catalog. We will discuss carefully the implications of these uncertainties in our main results.

Galaxy sizes are circularized effective radii obtained from the 2D Sersic fit using the PyMorph package (Vikram et al. 2010), which can fit seeing convolved two components models to observed surface brightness profiles. The authors performed bulge to disk and single Sersic decompositions to $\sim 7 \times 10^5$ galaxies from the SDSS DR7. The algorithm is described and tested in Meert et al. (2012). In particular, the sky estimate and how it affects size measurements is fully discussed in the mentioned work. For what concerns our work, the important result is that sizes are unbiased with a typical scatter < 0.1 dex (which depends on luminosity). For consistency with high redshift works we use here the sizes estimated from single Sersic fits which are shown to be less accurate than the ones obtained with two component models (Bernardi et al. 2012). We have checked though that our results are

¹http://gepicom04.obspm.fr/sdss_morphology/Morphology_2010.html

²<http://gax.shao.ac.cn/data/Group.html>

unaffected by that choice.

Mass to light ratios have been obtained from the MPA-JHU DR7 release³. They are derived through SED fitting using BC03 synthesis population models (Bruzual & Charlot 2003) and a Kroupa IMF following the procedure presented in Kauffmann et al. (2003) and Salim et al. (2007). We then convert to stellar masses by multiplying the M/L of each galaxy by its luminosity estimated from the best fit Sersic model. In order to compare to models, we also apply a 0.05 dex shift to convert to a Chabrier IMF following Bernardi et al. (2010). The typical error expected for photometrically derived stellar masses is ~ 0.2 dex which is the value that will be used in the following (e.g. Bernardi et al. 2010).

The final sample contains $\sim 12,000$ ETGs with $\log(M_*/M_\odot) > 10.5$ and $z < 0.09$, living in groups and clusters with halo masses from $M_h/M_\odot \sim 10^{12.5}$ to $M_h/M_\odot \sim 10^{15}$.

3. Results

3.1. Mass-size relation of ETGs in different environments

Figure 1 shows the observational median stellar-mass relation for centrals, satellites and all galaxies living in haloes of increasing mass, typically corresponding to field, group and cluster environments. Central galaxies are defined in all this work as the most massive galaxies in a given halo. For some groups, the central is not the same galaxy defined by Yang et al. (2007) because we reprocessed stellar masses using the Sersic luminosity as explained in section 2. The main results remain however unchanged when using the original definition. Our first result is that the mass-size relation of satellites and central galaxies do not show any significant trend with environment, i.e they present similar mass-size relations independently of the mass of the host. We confirm the preliminary results by Weinmann et al. (2009) but with a much larger sample and better defined sizes and morphological classification. We notice however than in a recent work using an independent dataset, Poggianti et al. (2012) found that the mass-size relation of cluster galaxies lies slightly below ($\sim 1\sigma$) the relation for field galaxies (see also Valentinuzzi et al. 2010). It is still unclear what can make the difference and it certainly requires further investigation. Morphological selection could for example play a role since Poggianti et al. (2012) sample seems to be dominated by lenticular galaxies which have been shown to be systematically smaller than elliptical galaxies at fixed stellar mass (Bernardi et al. 2012; Huertas-Company et al. 2012). In any case what seems to arise from these works is that if there is a difference with environment it must be small.

³<http://www.mpa-garching.mpg.de/SDSS/DR7>

Moreover, at fixed halo-mass, satellites and centrals present similar mass-size normalizations (fig. 2) and scatters which suggests that the mass-size relation is universal, independently of the position of the galaxy in the halo. In the following, we will try to understand how this lack of dependence with environment fits in the expected hierarchical growth of ETGs.

3.2. $M_h - \gamma$ relation of massive ETGs

The fact that galaxies of similar mass share similar size distributions irrespective of their environment, does not directly rule out some intrinsic environmental dependence. In fact, the intrinsic scatter of the mass-size relation for massive ETGs (~ 0.2 dex - e.g. Bernardi et al. 2011, 2012, see also fig. 1) puts an upper limit to that effect, i.e. galaxies in massive haloes can be at most a factor 3 ($2 \times 10^{0.2}$) larger than the same galaxies living in small haloes. As a result, the detection of the signal might be difficult given the observational uncertainties in the different variables at play (sizes, halo masses, galaxy classification, stellar masses) which can reduce any observed trend (see sections 4.2 and 4.4).

Therefore, in the next two sections we want to focus on the high mass end of the mass function and look in detail for environmental effects taking into account as much as possible the effects of observational biases and errors, while comparing to the predictions of some state-of-the art semi analytical models.

To this purpose we analyze the $M_h - R_e$ relation, which gives the median size of ETGs at fixed stellar mass as a function of environment. While there is a well known correlation between the mass of the halo and the stellar mass of galaxies populating it (e.g. Lin & Mohr 2004), the scatter of that relation is large enough so that galaxies of a fixed stellar mass populate a large range of haloes (fig. 3), allowing a study of environmental effects at fixed stellar mass.

Our main results are shown in figure 4 for central galaxies in two stellar mass bins ($11 < \log(M_*/M_\odot) < 11.5$ and $11.5 < \log(M_*/M_\odot) < 12$) and for satellite galaxies in one single stellar mass bin (very massive satellites only exist in massive haloes). We use stellar mass bins used relatively large to increase statistics and minimize the impact of errors in stellar mass (~ 0.2 dex). However, this choice could induce spurious correlations between size and environment, since more massive galaxies and hence larger, preferentially live in massive haloes given the existing correlation between M_h and M_* . In order to get rid of this effect, we use normalized sizes (γ) following a similar procedure than the one explained in Newman et al. (2011) and Cimatti et al. (2012):

$$\text{Log}_{10}(\gamma) = \text{Log}_{10}(R_e) + \beta \left(\frac{(M_*^{up} - M_*^{low})}{2.0} - M_* \right) \quad (1)$$

where, β is the slope of the $M_* - R_e$ relation in the considered mass interval, R_e is the effective radius and M_* , M_*^{up} and M_*^{low} are the logarithms of the stellar mass and the upper and lower limits of that stellar mass interval respectively.

Finally, since we are interested in relative differences between the different environments, we normalize all sizes to the median size in the halo mass bin $M_h/M_\odot = 10^{12.5} - 10^{13}$. That way, by definition, all median sizes in that halo are equal to one. Uncertainties on the median values are computed through bootstrapping, i.e. we repeat the computation of each value 1,000 times removing one element each time and compute the error as the scatter error of all the measurements.

The most striking result is that the $\gamma - M_h$ relation is essentially flat independently of the stellar mass and of the position of the galaxy in the halo, i.e. sizes of massive ETGs are the same at all environments within the errors. In the next section we discuss the robustness of this result to observational errors and selection effects and compare it to some model predictions.

4. Discussion

4.1. Selection effects

While in the expansion scenario (see sec. 1) galaxies puff-up at constant stellar mass, in the merger model galaxies contemporarily also grow in mass by a factor 2-3 (Naab et al. 2009). Studying environmental dependence at fixed stellar mass may thus not be the ideal choice to test hierarchical scenarios even though we expect this fact to have a small effect in our results given the relatively large bins of stellar mass used (0.5 dex). What seems clear is that, to be effective in increasing sizes, minor mergers should preferentially increase the outskirts of the stellar distributions leaving the central regions more or less intact. Therefore, one alternative way to probe environmental effects could be to fix central mass density instead of total stellar mass density. Results are shown in figure 5 for central galaxies with central densities that roughly correspond to galaxies of $\sim 10^{11}$ solar masses. Projected central densities are computed in the inner 1 Kpc, using the best fit profiles as done for instance by Saracco et al. (2012). The observed trend in the $M_h - \gamma$ plane is still consistent with flat, confirming our previous results. We notice that the β normalization factor to compute γ (see eq. 1) is larger than the one used at fixed stellar mass since the mass-size relation is

steeper when the central mass density is fixed (see middle panel of figure 5).

An observational signature of merger models (see sec. 1) should be a systematic increase in the Sersic index with time, while the expansion scenario tends to preserve the original profile, at least up to 50% of mass loss (Ragone & Granato 2011). Thus, in a hierarchical scenario, more evolved systems (i.e., with more mergers) are expected to have, on average, higher Sersic indices (e.g., Hopkins et al. 2009). By selecting only early-type galaxies in our study, we thus might be biased towards higher values of the Sersic index, and not being properly considering an enough wide dynamic range to probe different growth histories. In other words, our selection of ETGs might artificially flatten the signal since we might be preferentially selecting objects with high Sersic index, with an assembly history possibly dominated by mergers, and missing objects with lower Sersic index mostly grown via insitu star formation (which could be more common in low density environments). In figure 6 we show that the Sersic index distribution of the selected galaxies is broad (even if dominated by high values) indicating that we are indeed probing different formation histories. The distributions are also similar if the selection is based on stellar mass or star formation (instead of morphology) and most importantly, our main results discussed previously remain unchanged.

4.2. Can errors wash out the signal?

As previously stated, the scatter of the mass-size relation for massive galaxies is not very large, a factor 1.5-2 typically. Therefore, the environmental signature is bounded to a factor 3 to 4 at most. It is important then to properly understand if the lack of dependence on environment we measure is a consequence of observational errors in the different parameters involved (M_h, M_*, R_e) that could wash out the signal or a real signature.

To that purpose, we investigate through Monte Carlo simulations what is the error required to wash out a possible existing signal. We first make the hypothesis that there is a maximum trend with environment within the constraints imposed by the scatter of the real mass-size relation i.e at fixed stellar mass, ETGs living in low mass haloes can at most be ~ 3 times smaller than their counterparts living in the most massive haloes (twice the scatter of the mass-size relation). Therefore, to each galaxy, given its measured stellar mass and size from the real data, we assign a halo mass following the median $M_* - M_h$ relation measured in the data plus a scatter. The latter is derived from the data but weighted with the relative difference between the measured size and the median size expected given the stellar mass of the considered galaxy (eq. 2).

$$M_h(M_*, R_e) = \overline{M_h(M_*)} + \sigma_{M_h}(M_*) \frac{R_e - \overline{R_e(M_*)}}{\sigma_{R_e}(M_*)} \quad (2)$$

This way, smaller galaxies at fixed stellar mass will preferentially be associated to smaller halos, always within the scatters of the real observations. For example, a galaxy which is 0.5σ below the median mass-size relation will also have an halo mass which is 0.5σ below the median $M_* - M_h$ relation. We then progressively add increasing random errors to stellar mass, size and halo mass. Results are shown in figure 7. The main conclusion is that, indeed, statistical errors tend to wash out the signal, especially errors in halo mass. Combining the three uncertainties, a real dependence on environment would not be detected if the error on each variable is of the order of three. Typical uncertainties on halo and stellar mass can reach these values, while for R_e we usual expect errors of 5-10%. The second row of figure 7 shows indeed the result of adding the expected typical errors in the three observables. The signal is slightly flattened but preserved.

These tests seem to indicate that the lack on environmental dependence we measure is a real trend in the data and not a consequence of observational errors, or that our uncertainties on stellar mass, sizes, and halo mass have been severely underestimated.

4.3. Effects of interlopers

As an additional check to estimate the effects of errors in halo mass and interlopers in the membership selection, we defined a smaller but robust control sample of spectroscopically confirmed members of massive clusters based on the selection of Aguerri et al. (2007). The sample is made of 88 clusters with known redshift at $z < 0.1$ from the catalogues of Abell et al. (1989), Zwicky et al. (1961), Böhringer et al. (2000) and Voges et al. (1999) that have been mapped by the SDSS-DR4 (York et al. 2000). Cluster membership has been obtained using the velocity information from SDSS-DR4 by a combination of two algorithms. In a first step the ZHG algorithm was applied. In a second step, the cluster membership was refined by the applications of the KMM algorithm. The final sample contains a total of 10865 galaxies as cluster members (see Aguerri et al. 2007 for more details). Halo masses of those clusters were estimated independently based on numerical N-body simulations using Eq (2) of Biviano et al. (2006) rescaled for cluster redshift and cosmology. The errors in the mass estimations were obtained by propagating the errors in this equation. Sizes, stellar masses and morphologies come from the same catalogs than for the main sample (see sec. 2). We still find similar results using this independent sample. The Pearson correlation coefficient between halo mass and size is ~ 0.1 proving that there is no correlation at the cluster scale

and also the values of γ are consistent with the ones measured from the field SDSS sample (fig. 8).

4.4. Model predictions

As detailed above, there have been mainly two types of theoretical ideas put forward in the literature to explain the structural evolution of massive, bulge-dominated galaxies. Here we focus mainly on hierarchical, merger models, and compare, in particular, with predictions from the Guo et al. (2010) hierarchical model and also with its variant by Shankar et al. (2013) in figure 9⁴

Galaxy progenitors are initially disk-like and after a major merger the remnant is considered to be an elliptical (though disk regrowth can happen). Minor mergers instead tend to preserve the initial morphology of the most massive progenitor but tend to increase the mass of the bulge and disk components via the aggregation of old stars and newly formed ones during the merger (e.g. Aguerri et al. 2001; Eliche-Moral et al. 2006).

The main difference between the two considered models is that the Guo et al. (2010) model does not consider gas dissipation during gas-rich major mergers, a feature that has instead been included by Shankar et al. (2013) by adapting the Guo et al. (2010) model. The latter model also assumes all mergers to strictly have null orbital energies (i.e., parabolic orbits), a feature which renders mergers more efficient in puffing up sizes, as detailed in Shankar et al. (2013) and references therein.

To properly compare observations with model predictions, we perform 1,000 Monte Carlo realizations drawn from the model catalogs, with subsamples of galaxies of the same number as in the SDSS sample in the halo mass range we consider. Model galaxies are selected to have $B/T > 0.5$ and to share the same stellar and halo mass intervals as in the observations. We also add to the model predictions typical errors expected from observations, i.e. 0.3 dex in halo mass, 0.2 dex in stellar mass and ~ 0.1 dex in size. Contamination from interlopers might also bias our results and has been taken into account in the models by substituting 20% (Yang et al. 2007) of each halo members with galaxies of the same stellar mass residing in the field. This reduces the increase of mean size with halo mass by up to

⁴We here stick with 3D normalized sizes from models with no luminosity dependent conversion to 2D sizes. Both models follow the hierarchical growth of galaxies along the merger trees of the Millennium simulation (Springel et al. 2005). In these models, bulges grow mainly via two mechanisms: mergers and disk instabilities. Mergers contribute essentially to build elliptical galaxies with large bulges ($B/T > 0.7$) while disk instabilities are more important in galaxies with intermediate $B/T=0.4-0.7$.

20%. For each Monte Carlo realization we compute the mean, and then extract, from the full distribution of means, the final mean and its 1-sigma error.

Once errors are properly inserted in the Monte Carlo simulations, the Guo et al. (2010) model seems consistent with the data at the 1-sigma level, while its variation by Shankar et al. (2013) seems inconsistent at about 2-3 sigma (we notice that without including errors both models would be inconsistent with the data at $2 - 3\sigma$). This is particularly interesting as the Shankar et al. (2013) variation to the Guo et al. (2010) model results in a significantly better fit to the overall local size-mass relation, as well as the size-age relation (Shankar & Bernardi 2009) of local early type galaxies, and incorporates the effects of detailed hydro-simulations. Clearly both modifications performed by Shankar et al. (2013) significantly increase environmental dependence, worsening the match to the data.

In principle, both mergers and disk instabilities contribute to the predicted trend of increasing size with host halo mass. The net effect of both processes is, however, convolved in the models, so it is not easy to discern the relative impact of each separate physical mechanism on the outputs. We have nevertheless checked that restricting the analysis to bulge dominated massive galaxies, those with $B/T > 0.7$, believed to have grown mostly by mergers (Shankar et al. 2013), models show less environmental dependence, especially at low halo masses, but still significant. So even mergers alone tend to predict some increase in sizes with environment. This is not unexpected, since the integrated history of massive galaxies residing today in more massive haloes, should be characterized by an higher incidence of mergers with respect to counterparts in less massive haloes, though the extent of the latter statement is model-dependent.

Overall, a variety of parameters contribute to the environmental dependence of sizes in the models, from the exact choice of dynamical friction timescale, to the level of stripping in merging satellites. Clearly, a detailed investigation of this is beyond the scope of the present work and will be presented in a dedicated work (Shankar et al. in preparation). What is relevant to the present work is that basic variations to state-of-the-art SAMs, tuned to provide a better match the local size-mass relation of massive early-type galaxies, can have non negligible repercussions on the exact dependence on environment, which proves to be an extremely powerful probe for galaxy evolution models.

When considering satellites, both models and observations show a lack of dependence of the galaxy-size with environment. This could be caused by satellite-satellite mergers being rarer in a hierarchical scenario (Angulo & White 2010), but also, stellar stripping could partly erase any increase in mass and size in galaxies pre-processed in group scale environments.

5. Conclusions

We have analyzed a sample of $\sim 12,000$ local ETGs from the SDSS DR7, selected in different environments. Our main results are the following:

- The mass–size relation of ETGs in the local Universe does not significantly depend on environment. At fixed stellar mass (or fixed central stellar mass density), galaxies residing in the centers of massive haloes have similar sizes than the ones living in less massive haloes. This is even true for the high-mass end of the galaxy population. We have checked through Montecarlo simulations, that a possible signal would have been detected even with a factor 3 error in halo mass, stellar mass and size, which implies that the flatness of the $R_e - M_h$ relation is an intrinsic property and not a consequence of observational uncertainties, or that our observational uncertainties have been severely underestimated.
- The mass-size relation does not depend either on the position of the galaxy in the halo, satellites and central galaxies follow similar mass-size relations.
- The two hierarchical models explored in this work (Guo et al. 2010 and Shankar et al. 2013) tend to find a dependence of size on halo mass for central massive ETGs ($\log(M_*/M_\odot) > 11.0$), i.e. they predict that galaxies in low mass halos ($\log(M_h/M_\odot) = 12 - 12.5$) should be 1.5 – 2.5 times smaller than galaxies living in massive end of the halo distribution ($\log(M_h/M_\odot) = 14 - 14.5$). When all source of errors are properly included in the models, the predictions are at variance with our observations for the Shankar et al. (2013) model at $2 - 3\sigma$ level, while we are in agreement with the Guo et al. (2010) model at 1σ . This proves the powerful of environment to constrain galaxy evolution models. We will reserve a full theoretical study of current predictions from hierarchical models in a separate work (Shankar et al., in prep.). Predictions for satellite galaxies are in agreement with observations.

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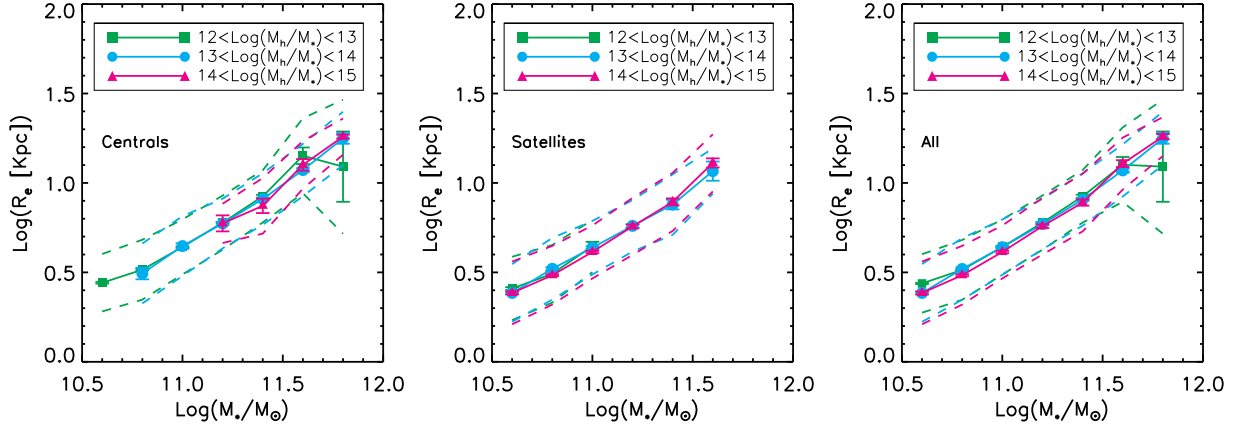


Fig. 1.— Median stellar mass-size relation for centrals (left panel), satellites (middle panel) and all ETGs (right panel) living in different halo masses. Error bars are errors on the medians computed through bootstrapping and dashed lines show the $1 - \sigma$ scatter.

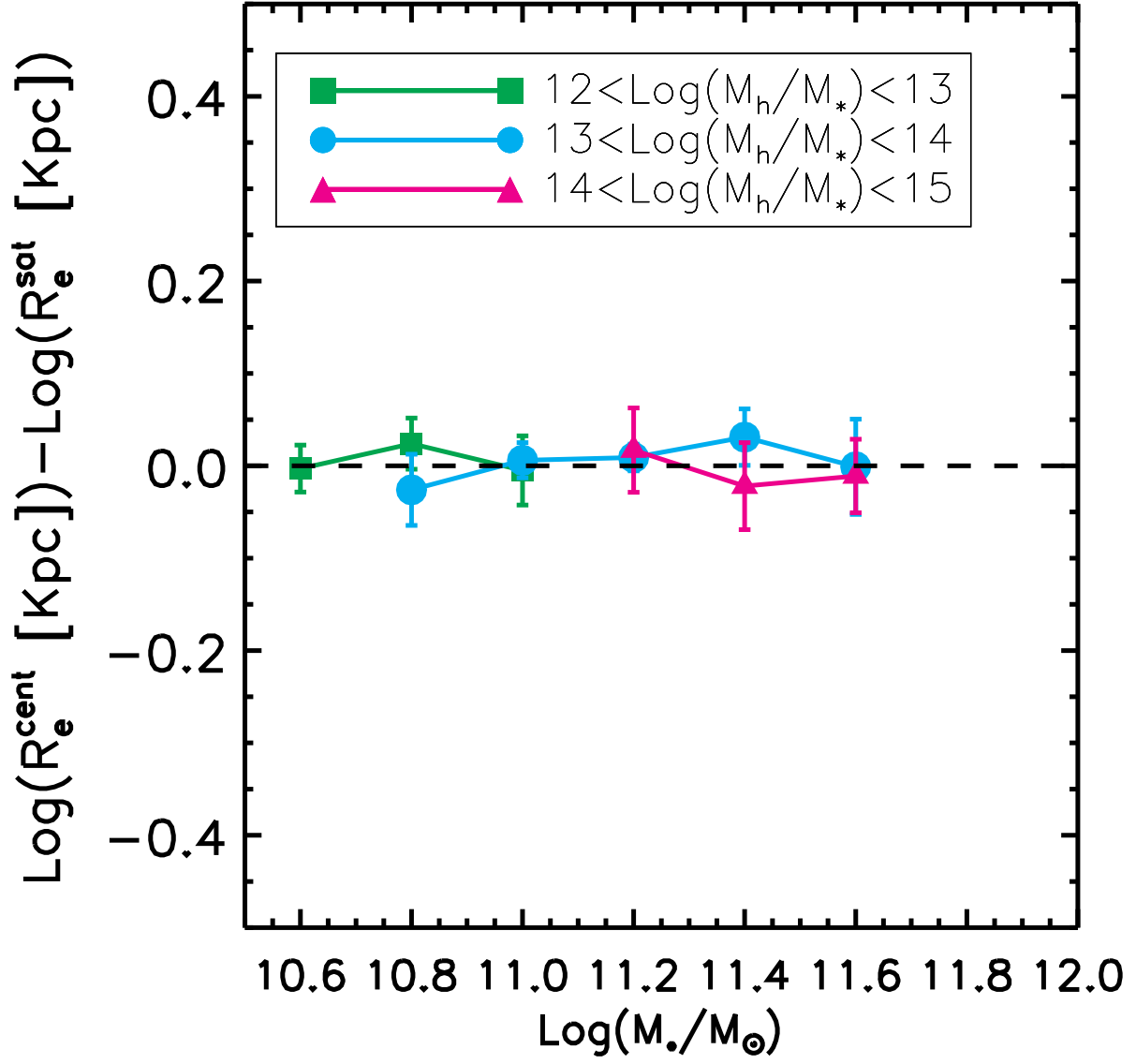


Fig. 2.— Median size ratio of centrals and satellite galaxies for different halo masses as a function of stellar mass.

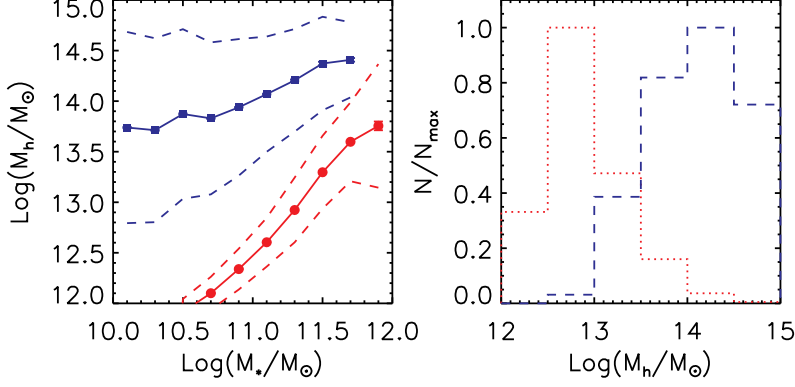


Fig. 3.— Left: Median M_* – M_h relation for central ETGs (solid red, filled circles) and satellites ETGs (solid blue, filled squares). Dashed lines show the $1 - \sigma$ errors. Right: Histogram of halo masses for ETGs more massive than 10^{11} . Dotted red: central galaxies, dashed blue: satellite galaxies.

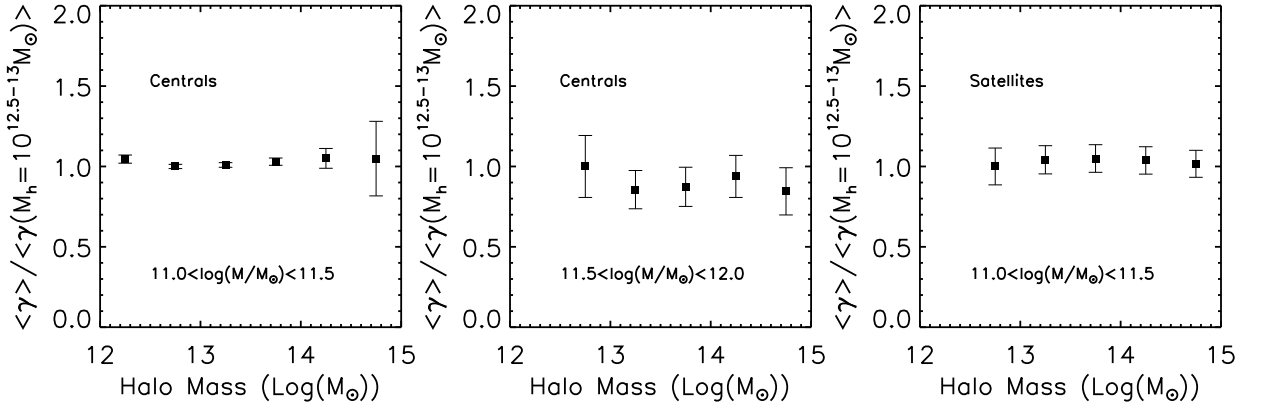


Fig. 4.— Size of central (left and middle panels) and satellites (right panel) ETGs as a function of halo mass in the SDSS in two stellar mass bins. Values have been normalized so that, by definition, the field observed value at an halo mass of $\log(M_h/M_\odot) = 12.5 - 13$ is equal to 1. Errors are errors on the median values computed through bootstrapping (see text for details).

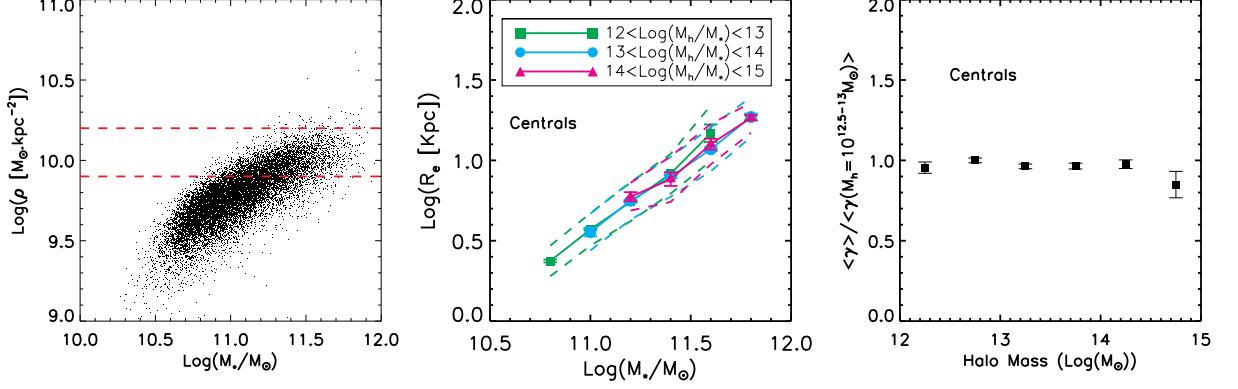


Fig. 5.— $M_h - \gamma$ plane at fixed central mass density. Left panel shows the relation between stellar mass and central density for central ETGs. Red lines indicate the range of central mass densities considered to produce the plots on the middle and right panels. The middle panel shows the mass-size relation for the selected galaxies in three environments. The right panel shows the $M_h - \gamma$ plane for ETGs with $10^{9.8} < \rho < 10^{10.1}$. The trend is still consistent with flat. Values have been normalized so that, by definition, the field observed value at an halo mass of $\log(M_h/M_\odot) = 12.5 - 13$ is equal to 1. Errors in models and observations are errors on the median values computed through bootstrapping.

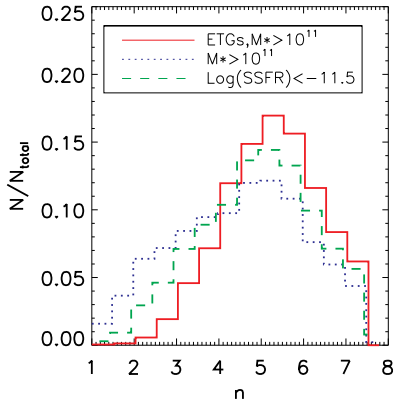


Fig. 6.— Sersic index distribution for galaxies with $\text{Log}(M_*/M_\odot) > 11$ for different selections.

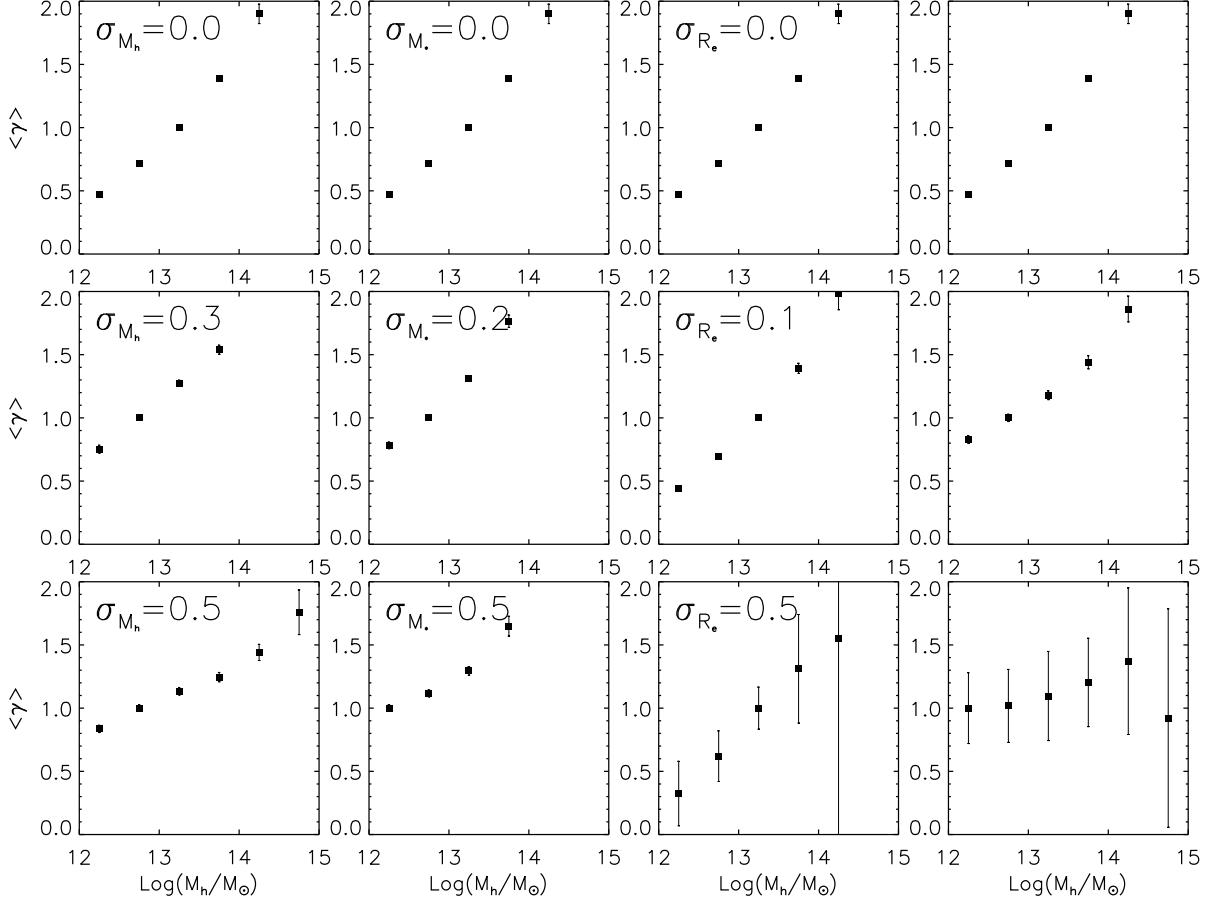


Fig. 7.— Results of Montecarlo tests to assess the sensitivity to observational errors of an eventual environmental effect on the sizes of ETGs. Top row shows the simulated $M_h - \gamma$ without errors. Second row shows the resulting $M_h - \gamma$ plane after adding the typical uncertainties on halo masses (0.3 dex, first column), stellar masses (0.2 dex, second column) and sizes (0.1 dex, third column) and all three combined (fourth column). The third row show the same relation with errors of 0.5 dex in M_h (first column), M_* (second column), R_e (third column) and all three together (fourth column). At least a factor 3 error in the three involved parameters simultaneously is required to wash out the signal while typical uncertainties expected do not remove it.

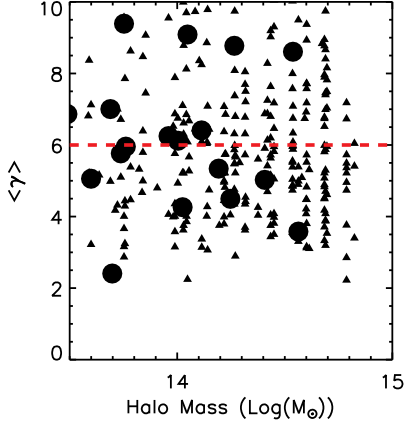


Fig. 8.— Mass-normalized size (γ) of central (big circles) and satellites (triangles) ETGs as a function of halo mass in the cluster sample of Aguerri et al. (2007). No correlation between size and halo mass is detected at the cluster scale (correlation coefficient is ~ 0.1). The red dashed line shows the median γ value measured in the SDSS field sample extrapolated to the cluster scale in order to check that there is no any significant trend.

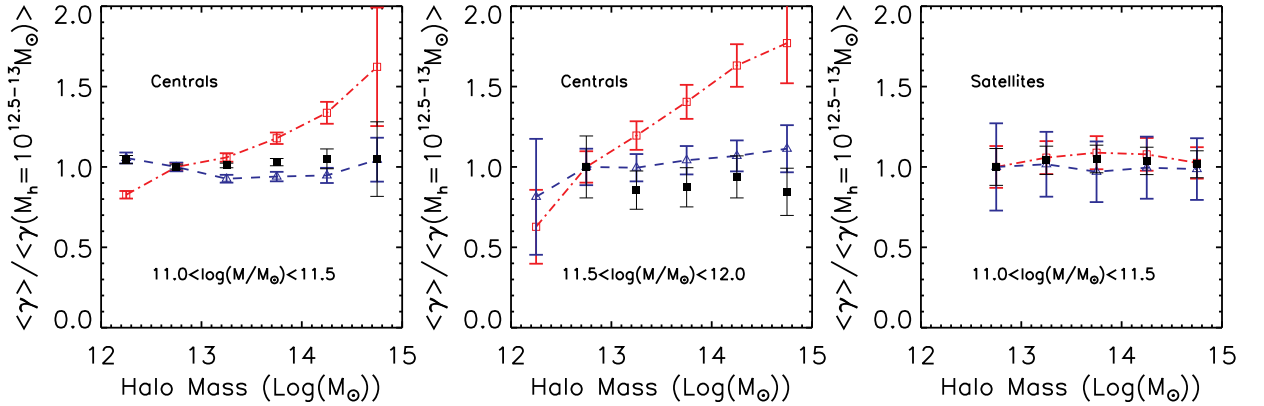


Fig. 9.— Same as figure 4 with model predictions. Size of central (left and middle panels) and satellites (right panel) ETGs as a function of halo mass in the SDSS in two stellar mass bins. Filled squares are the observed values. Red dashed-dotted and blue dashed lines show the expected relation from Shankar et al. (2013) and Guo et al. (2010) models respectively at $z = 0.1$ in similar stellar mass ranges. Values from models and observations have been normalized so that, by definition, the field observed value at an halo mass of $\log(M_h/M_\odot) = 12.5 - 13$ is equal to 1. Errors are errors on the median values computed through bootstrapping.